Space Interferometry Mission

Microarcsecond Precision Astrometry

S.C. Unwin (Jet Propulsion Laboratory, California Institute of Technology)

unwin@huey.jpl.nasa.gov

What is SIM ?

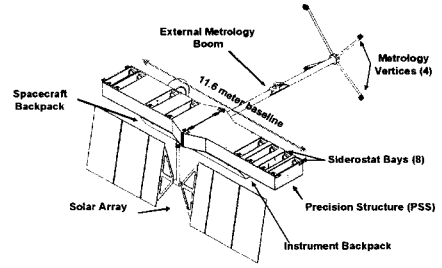
SIM is NASA's first space-based long-baseline interferometer designed for precision astrometry. SIM will extend the reach of precision astrometry to cover the entire Galaxy, and will address a diverse set of topics in stellar astrophysics and Galactic astronomy, and will be an extraordinary tool for discovering planets. The principal science topics for SIM include:

- Astrometric search for planets with masses as small as a few Earth masses around the nearest stars
- Characterization of planetary systems: mass distribution; planet frequency; multi-planet systems
- Ages of globular clusters
- Calibration of the cosmic distance scale using Cepheids and other indicators
- Stellar Dynamics of the Galaxy
- Accurate masses for sub-stellar companions
- Orbits of globular clusters an satellite galaxies
- Dynamics and evolution of binary stars
- Astrophysics of luminous stars
- Rotational parallaxes to spiral galaxies
- Dynamics of the local universe

SIM is being developed by NASA's Jet Propulsion Laboratory, a division of the California Institute of Technology. The mission is currently in Formulation Phase ('Phase A/B'). Implementation Phase will start in 2002, with launch expected in mid-2006. In October 1999, the Project selected one of two major architectures under consideration for the SIM design. JPL is now busy developing this design in more detail, in partnership with TRW and Lockheed Martin.

The SIM Instrument

SIM comprises three Michelson interferometers on a 10-m structure. Collectors at each end of the structure contain afocal telescopes which compress the input beam from a diameter of 0.3 m. Two telescope pairs observe bright guide stars, to stabilize the optical system, and a third pair observes the science target. The instrument will be launched into an Earth-trailing solar orbit (like SIRTF).



The CCD camera on SIM is designed to detect the exact position of the white-light envelope of the interference fringes between the two 33-cm entrance apertures. A laser metrology system measures the **internal delay** - the optical path difference (OPD) between the two arms of the instrument. This internal delay, measured repeatedly over the 5-year mission, allows us to calculate the 5 basic astrometric parameters of each target star: Position (RA and dec); proper motion (in RA and dec); and parallax.

SIM Observing Modes

Global astrometry

SIM will achieve an accuracy of 4 **microarcseconds** in absolute position for stars as faint as 20 magnitude. It will set up and maintain an **astrometric grid** (*see below*) of approximately 3000 stars down to about 12 mag, as a reference system for astrometry of science targets.

Narrow-angle (local) Astrometry

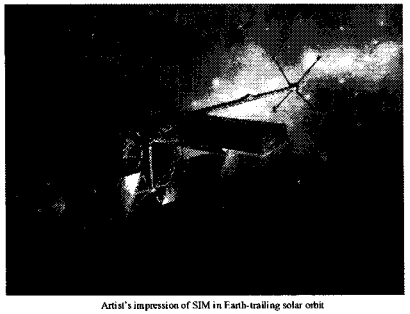
In this mode, the instrument measures relative positions between the target star and several reference stars within a radius of 0.5 deg. These nearby stars define a local reference in which the SIM accuracy will be **1 microarcsecond** in a 1-hour observation, cycling between target and references stars.

Aperture Synthesis Imaging

SIM operates as an aperture synthesis imager, provide a fully diffraction-limited aperture of 10m in the optical band. The mission is required to demonstrate this capability for future imaging missions, such as the *Terrestrial Planet Finder* (TPF). By rotating the instrument, the (u,v) coverage will allow SIM to make **10-milliarcsec resolution** images of relatively complicated targets, with high dynamic range. An example of an imaging target for SIM could be a nearby active galactic nucleus with strong H-α line emission near its center. By imaging the line-emitting gas, SIM will measure the mass distribution in the nucleus.

Fringe Nulling

This capability is a technology demonstration for a the *Terrestrial Planet Finder* . In nulling mode, the light paths through the instrument are adjusted to place a dark fringe (or 'null') on the detector. This cancels most of the light from the bright central star, allowing off-axis light from a planet close to the star to be detected. SIM will be required to demonstrate on-axis suppression on a bright star, to a level of **1 part in 10^4**.



Artist's impression of SIM in Earth-trailing solar orbit

Performance Summary

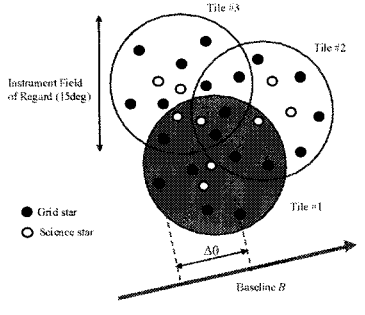
Wide Angle astrometric accuracy (1-D, 1-σ)	4 μas (end of 5-yr mission)
Narrow Angle astrometric accuracy (1-D, 1-σ)	1 μas (in 1 hour)
Instrument Field of Regard	15 deg
Instrument throughput (photon noise contribution to single 1-D measurement, 1-σ)	7.3 μas in 50 minutes
Synthesis Imaging resolution	10 mas (at 0.7 μm)
Aperture plane (*u,v*) coverage, evenly distributed	400 points
Nulling depth (on-axis suppression)	10^{-4}

SIM Astrometric Grid

SIM global astrometry requires an all-sky reference grid, to which positions of target objects are referenced. SIM observes and maintains this grid by observing a set of overlapping 'tiles', akin to a plate survey. The major parameters of the grid are:

Number of reference stars	3000
Mean star magnitude	V < 12
Accuracy of star positions	4 microarcsec RMS in RA and dec at end of 5 year mission
Estimated number of quasars	50 (tie to inertial frame)
Average number of stars per tile	12
Average number of (1-D) visits	112 (per star)
Sky coverage	All sky

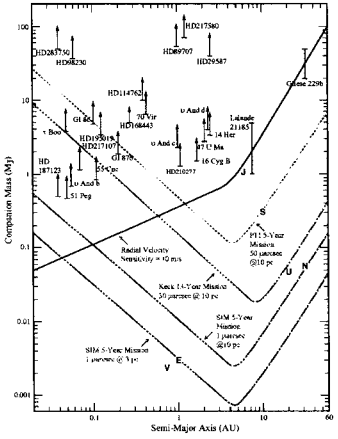
Assembling a catalog with these characteristics will be a major challenge. The astrophysical selection will be metal-poor K-III giants, at 1-4 kpc distance. The hardest requirement is the elimination of perturbations due to binary companions; 4 microarcseconds requires eliminating not only stellar companions, but also sub-stellar companions below the brown-dwarf mass range.



Searching for Planets

One of SIM's primary scientific goals is the detection of low-mass planets around nearby stars. SIM will be the only instrument for the foreseeable future capable of approaching Earth-sized planets. The figure below shows the 'search space' of planet mass vs. planet orbital radius. SIM is complementary to the current techniques using stellar spectroscopy measurement of radial velocity. RV is more sensitive to short-period planets. SIM's astrometric method is more sensitive to long-period planets.

SIM will detect many new planets, and will obtain full orbital parameters for the multiple-planet systems recently discovered.



Search space for planet mass vs. planet orbital radius. Known planets are indicated as lower limits (due to the sin *i* ambiguity). Curves show the current radial velocity capability (10 m/s), and the astrometric sensitivity of the Keck Interferometer SIM and SIM. Note the large region of this parameter space which SIM can explore.

Research Opportunities with SIM

SIM Preparatory Science Program

Awards from the second year of the Preparatory Science Program (a NASA Research Announcement) were recently announced. This NRA was focused primarily on selection of stars for the SIM astrometric grid. NASA expects to issue a NRA for a third year, in late 2000.

Michelson Interferometry Summer School

A third Michelson Summer School on Interferometry will be held in Berkeley, California, August 21-25, 2000. Details will be available on the SIM web site. As in previous years, students and researchers new to the field will attain a solid base in the principles and applications of optical and infrared interferometry. Materials from the second Summer School are available at:

`http://sim.jpl.nasa.gov/michelson/viewgraphs.html`

Michelson Fellowship Program

Fellowships are offered annually to young researchers with the goal of developing expertise in optical interferometry and its astrophysical applications. Graduate student fellowships support students at US universities and research institutions for three years. Postdoctoral Fellowships are awarded normally for two years with an extension to three years. Application details are available on the SIM web site.

For More Information on SIM

- Pick up a copy of the book "Space Interferometry Mission - Taking the Measure of the Universe" is available which describes the science, the instrument, and the mission.
- Pick up a copy of the SIM Science Working Group's (SIMSWG) Final Report (February 2000). The SIMSWG was chartered by NASA to explore the fundamental science enabled by SIM's microarcsecond precision. The Report describes the wide-ranging science impact of SIM.
- Sign up (on the web site) for the `SIM Newsletter` distributed by e-mail about every 2 months.
- Or visit the SIM web site: `http://sim.jpl.nasa.gov/`